

# **Development of a 1K x 1K GaAs QWIP far IR imaging array**

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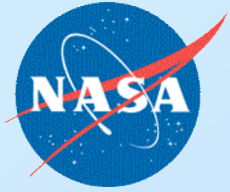
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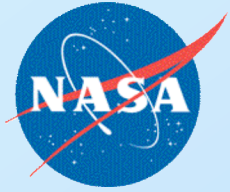
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**June 23, 2004**



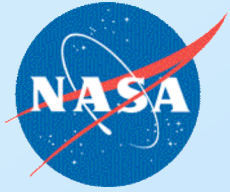
# Overview

- **Background and Project Goals**
- **Applications**
- **Design and Fabrication**
- **Test Results**
- **Near-Term Improvements**
- **Summary**



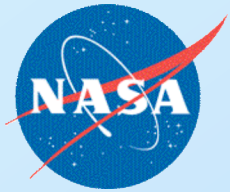
# **Background and Project Goals**

- **Design and model a far IR GaAs QWIP**
- **Fabricate a 1K x 1K GaAs QWIP array**
- **Hybridize to a silicon ROIC**
- **Thin and package the device as an FPA**
- **Characterize the device operation and performance**
- **Identify technological deficiencies**



# Applications

- **Studying numerous Earth science parameters such as:**  
Troposphere and stratosphere temperature; identifying trace chemicals; measuring cloud layer emissivities, droplet/particle size, composition and height; CO<sub>2</sub> absorption; tracking dust particles (from the Sahara Desert, e.g.); coastal erosion; ocean/river thermal gradients and pollution; monitoring deforestation of tropical rain forests, studying volcanic SO<sub>2</sub> and aerosol emissions
- **Ground based astronomy**
- **Medical instrumentation**
- **Commercial Agricultural Analyses:**  
Monitoring crop health; monitoring food spoilage, ripeness and contamination; location and identification of unwanted (alien) vegetation; location of forest fires and residual warm spots
- **Scientific Instrumentation:**  
Analyzing radiometers and other scientific equipment used in obtaining ground truthing and atmospheric data acquisition; IR microscopy (identifying hot spots on ICs); industrial equipment for monitoring effluents from industrial operations such as paper mills, mining and power plants
- **Potential earthquake prediction**
- **Locating new sources of spring water**



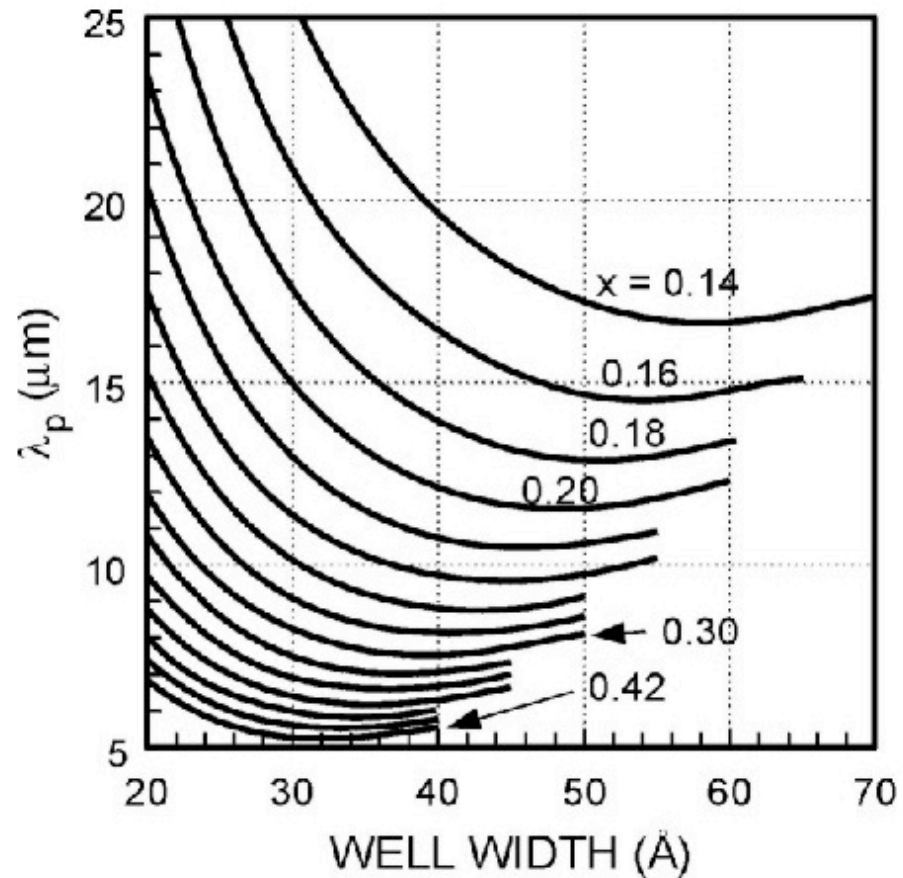
# QWIP Array Design

- **Design criteria:**

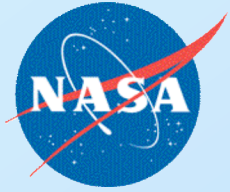
$\lambda_p = 9 \mu\text{m}$ ,  
total superlattice thickness  $\approx 3.5\mu\text{m}$ ,  
maximum operating temperature

- **For the GaAs/Al<sub>x</sub>Ga<sub>1-x</sub>As superlattice system:**

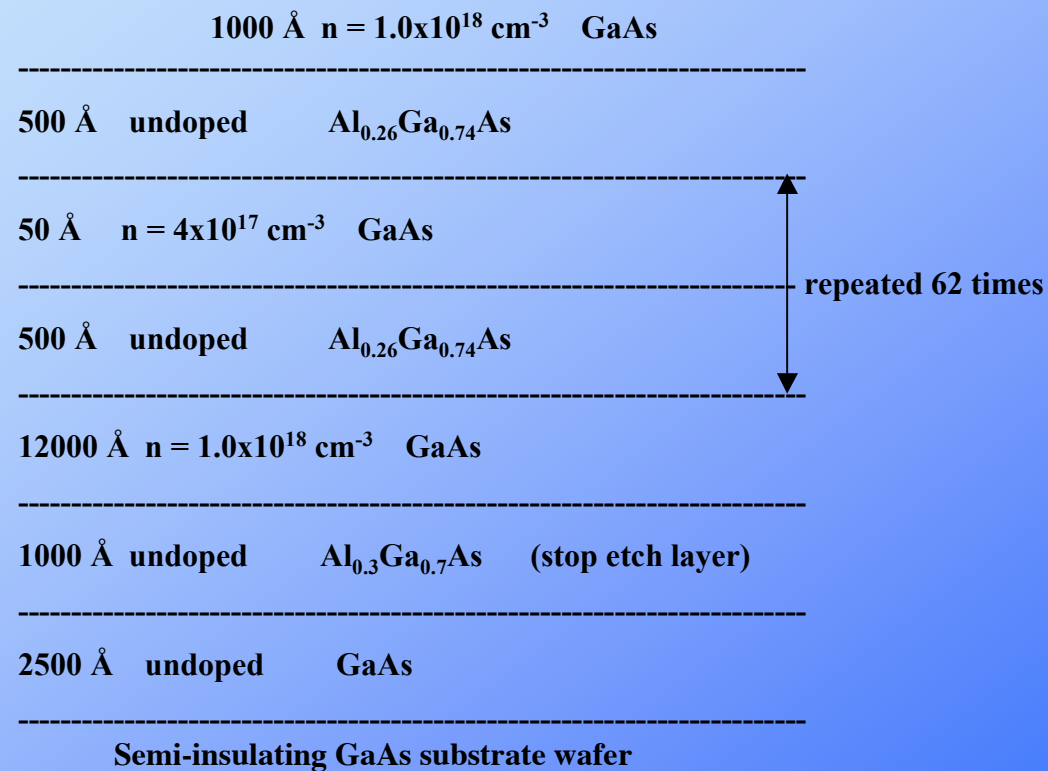
GaAs well width,  $w = 50 \text{ \AA}$   
Blocking layer =  $500 \text{ \AA}$   
 $x = .26$   
number of periods = 62



The calculated detection peak wavelength vs. quantum well width for different values of Al molar ratio.



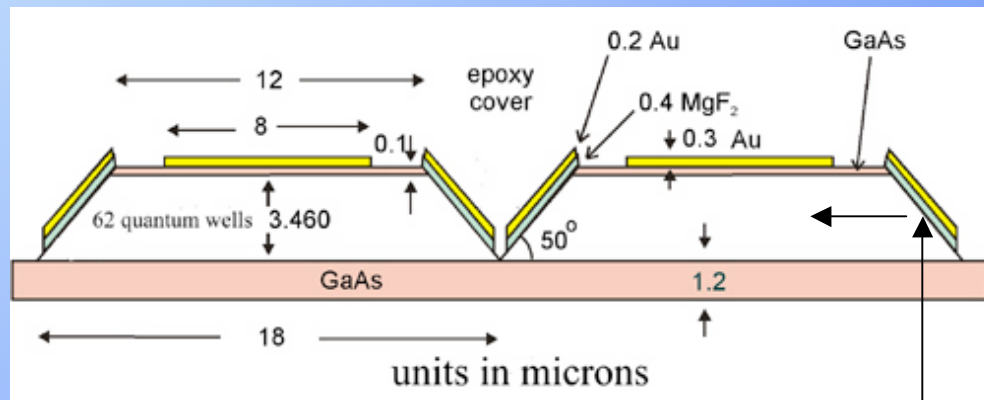
# Superlattice Structure/MBE Recipe





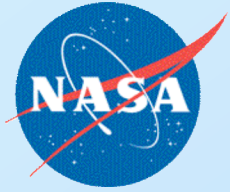
# Fabrication

- QWIPs do not interact with normal incidence radiation--require some form of structure to deflect radiation parallel to the surface.
- A corrugation (sawtooth) structure provides  $90^\circ$  deflection coupling light into the QWs.



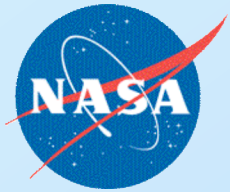
Incident photons are reflected into the Quantum Wells

- Dark current/sensitive volume is reduced which leads to an effective improvement in QE over other optical coupling methods.

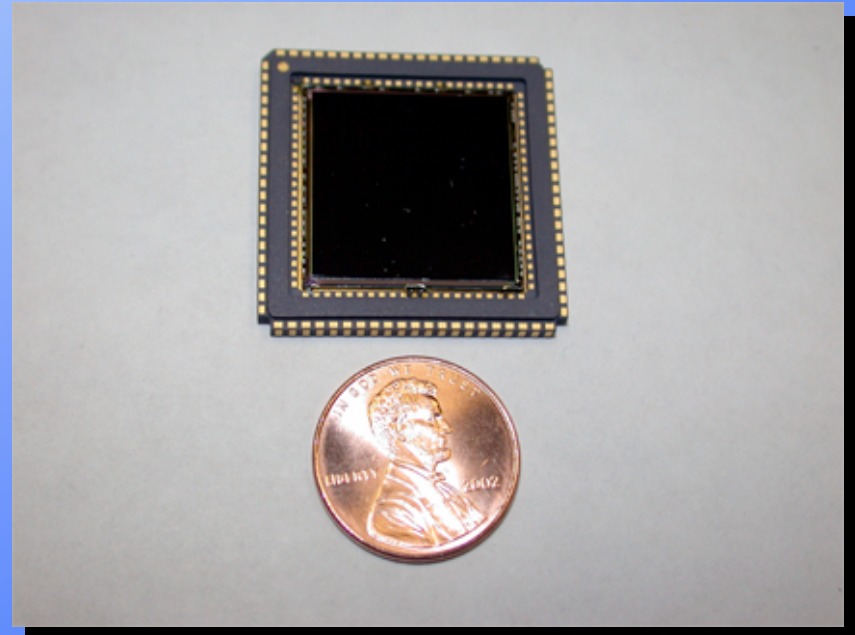
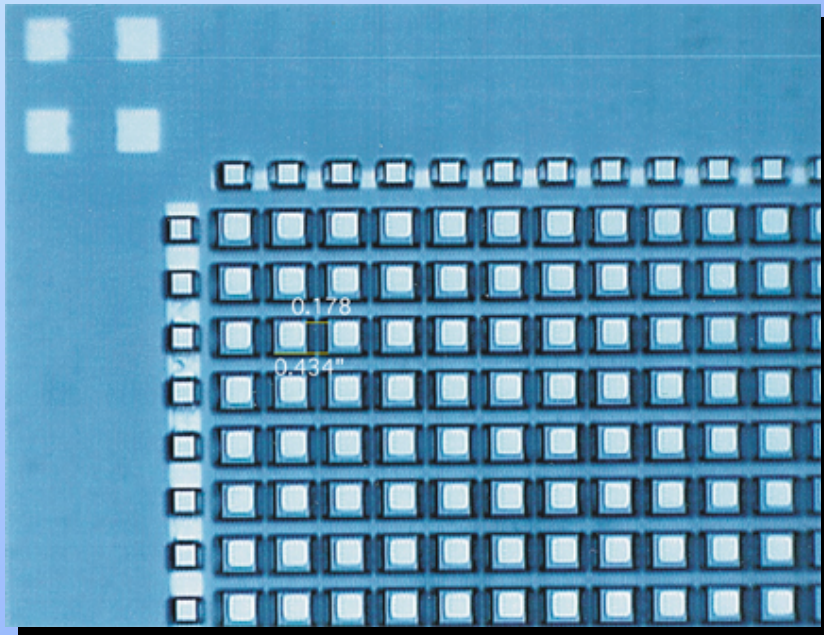
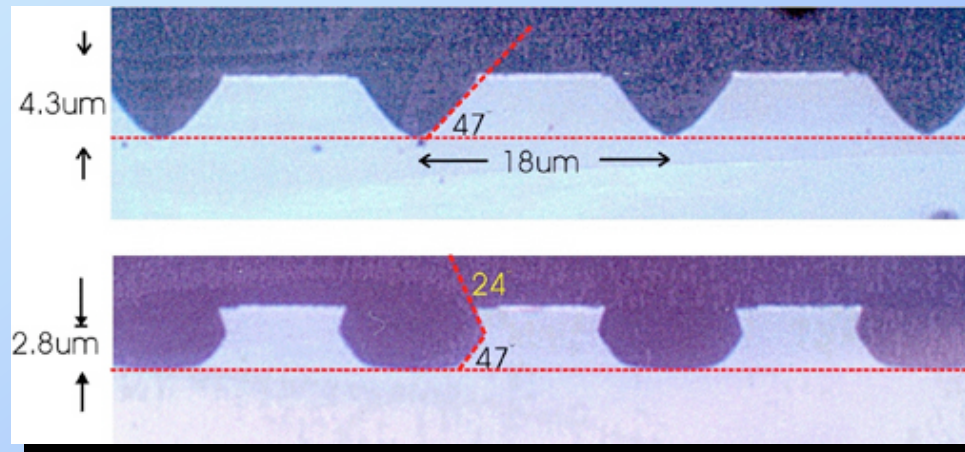


# Device Fabrication

- Starting material was a 3 inch diameter GaAs wafer
- The superlattice recipe and wafers were sent to IQE for MBE layer growth
- Wafers were processed in Goddards Detector Development Laboratory
- 3 mask steps required:
  1. Detector mesa formation
  2. The ohmic contacts for the indium bumps
  3. The insulator and metal reflector definition
- Wafers were sent to Rockwell Scientific for indium processing, dicing and hybridization
- Hybrids were temporarily mounted in 84 pin LCCs and screened at room temperature
- Candidates were sent to JPL for thinning, repackaging and then returned to the Goddard/ARL team for testing



# Device Structure





# Expected Performance Results

## Quantum Efficiency

$$\eta(\alpha, p, t) = \frac{4n}{(1+n)^2} \left\{ \frac{1}{p} \left[ t + \frac{e^{-\alpha p}}{2\alpha} (1 - e^{2\alpha t}) \right] + K_0 \right\}$$

$\eta$  = quantum efficiency

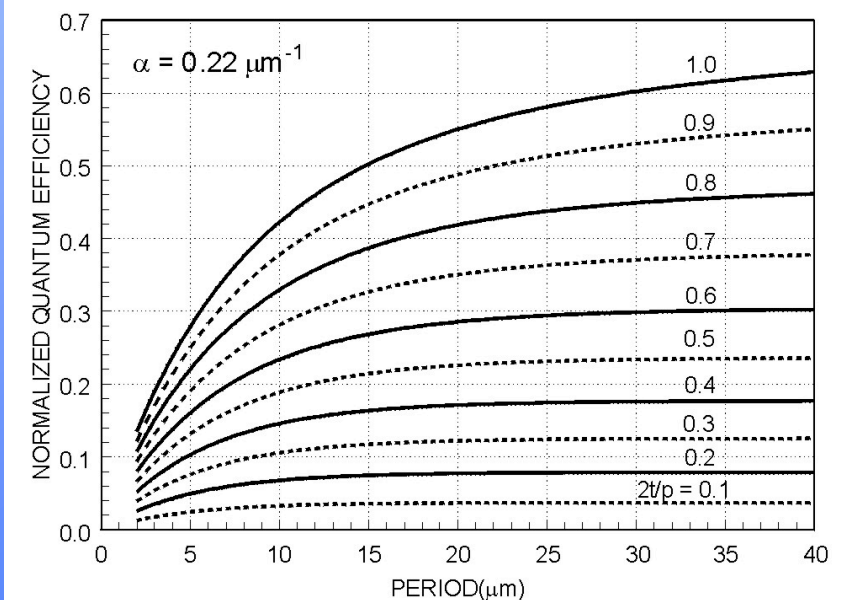
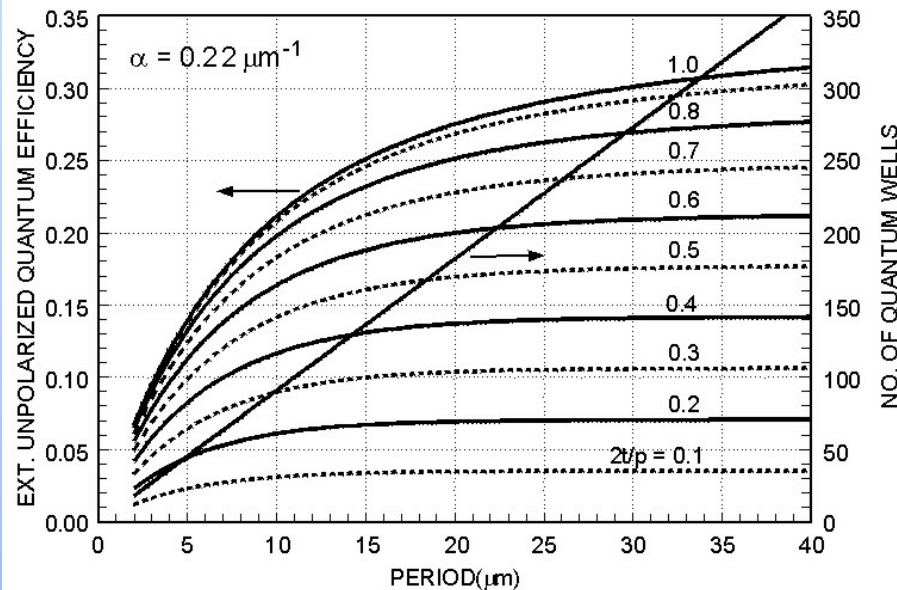
$n$  = index of refraction (3.34)

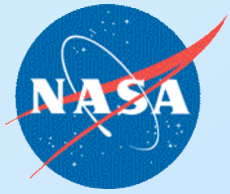
$\alpha$  = absorption coefficient ( $.22 \mu\text{m}^{-1}$ )

$p$  = corrugation period ( $18 \mu\text{m}$ )

$t$  = corrugation height ( $3.5 \mu\text{m}$ )

$K_0$  = endwall QE contribution

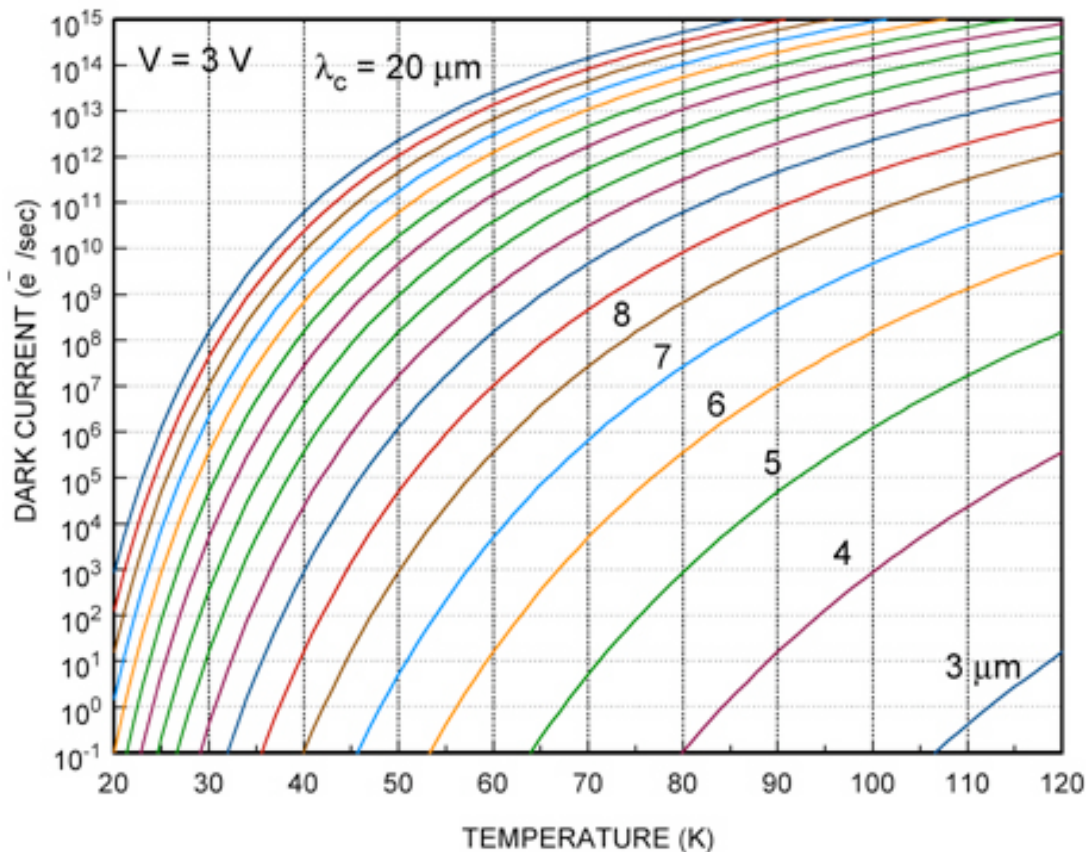




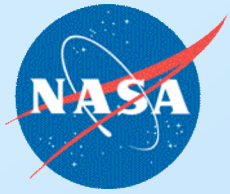
# Expected Performance Results

## Dark Current

Calculated dark current as a function of temperature and cutoff wavelength for an 18 x 18  $\mu\text{m}$  pixel with -3v bias.

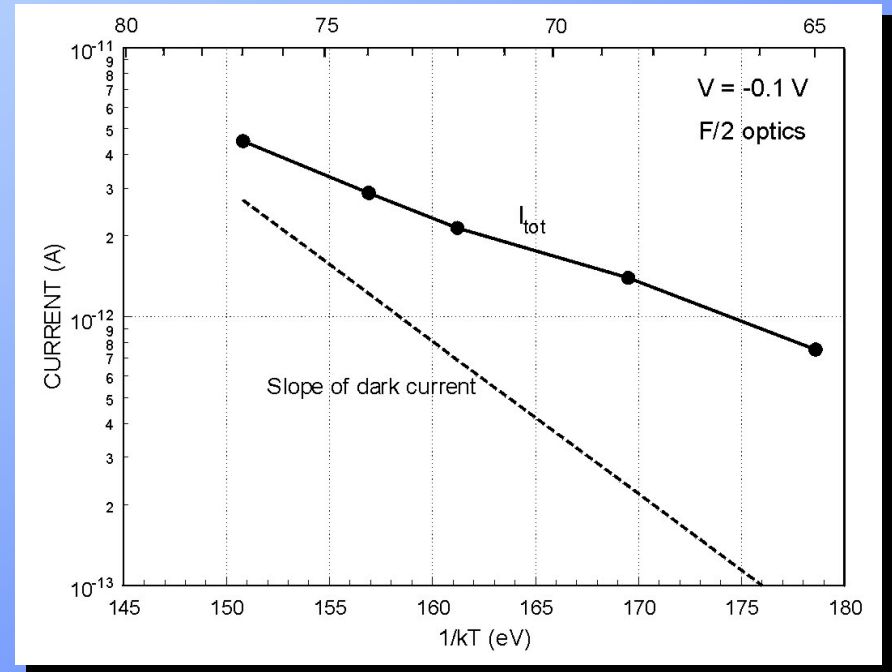
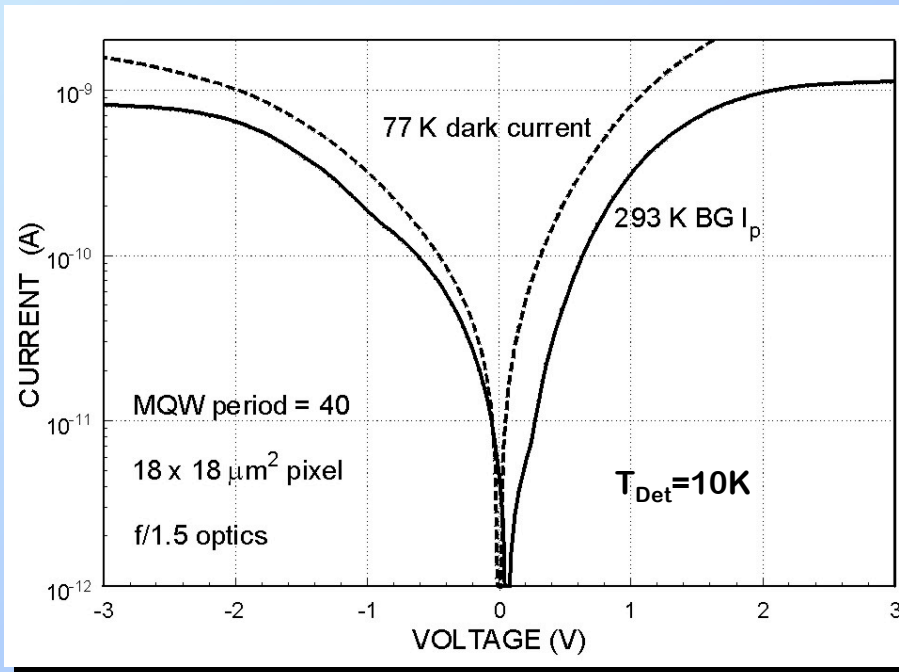


$$I(V, T) = I_0(V) e^{-\frac{E_a}{kT}}$$

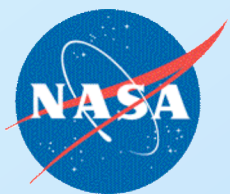


# Experimental Results

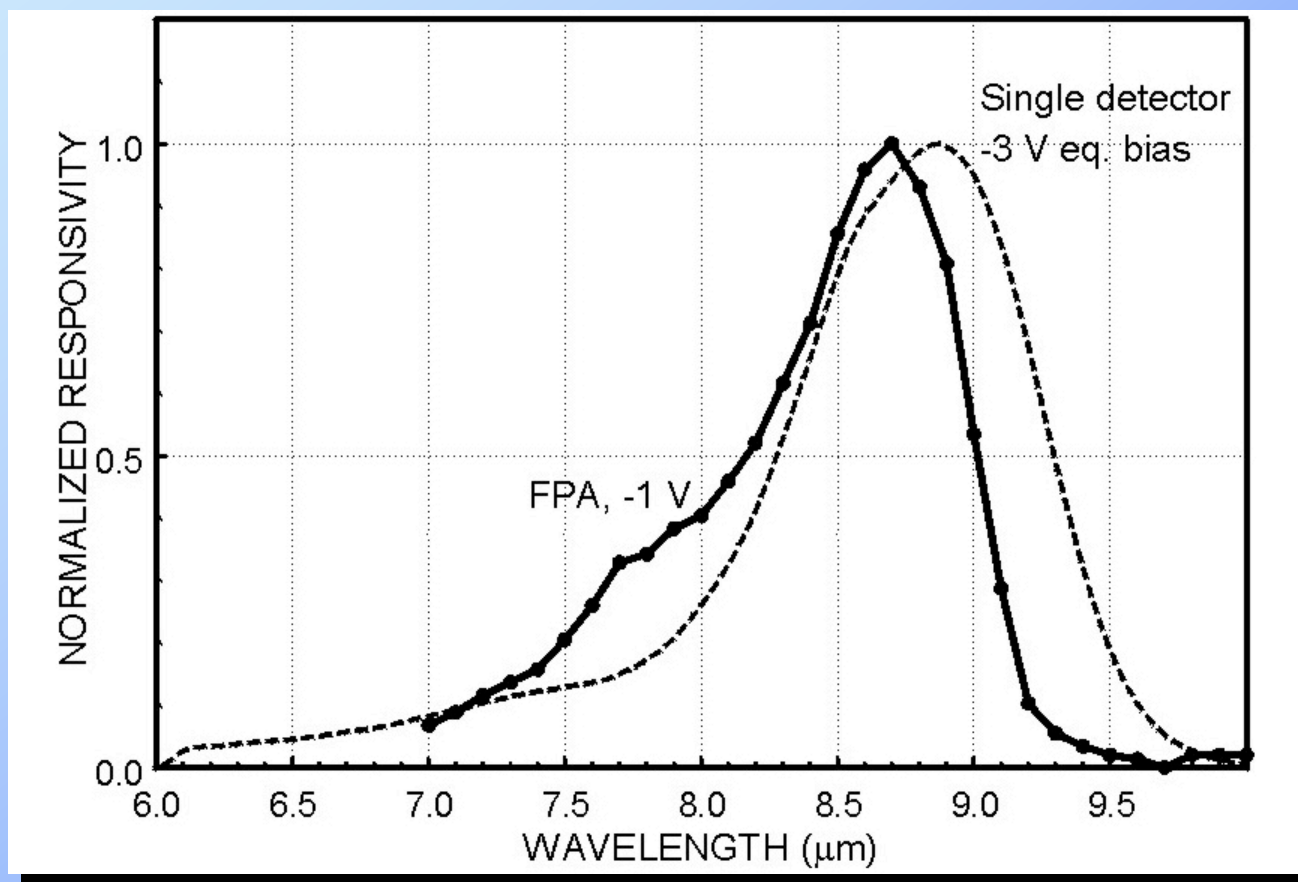
## Measured QWIP Current Generation



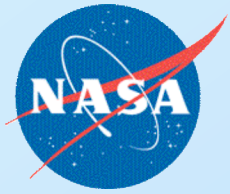
Left--large area detector. Right--total current generation with 293 K background signal (-0.1v bias).



# Measured Spectral Response



Spectral response measured with a grating monochromator at .1 μm intervals over the 7-10 μm range (T=65 K).



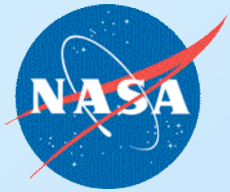
# QWIP Imaging

**2 quadrant image  
at 77K**



**2 quadrant image  
at 74K**



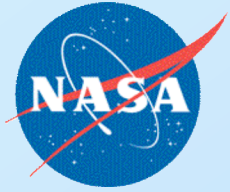


**2 quadrant image  
at 65 K**



**1 quadrant image  
at 65 K**





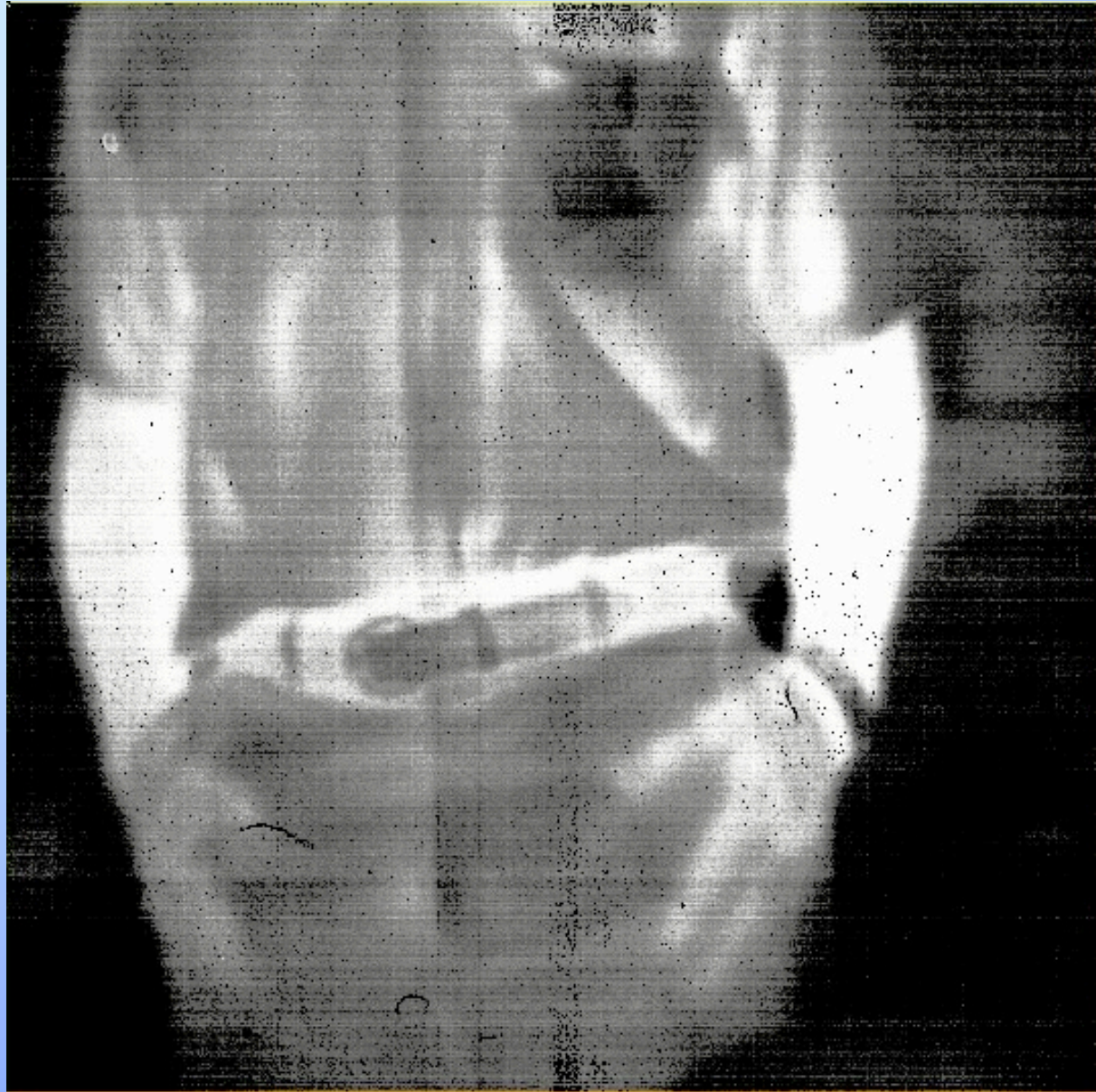
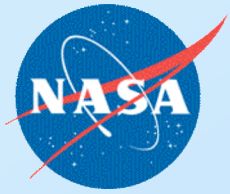
# Near Term Improvements

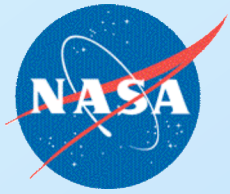
**Experienced a variety of "new development" problems:**

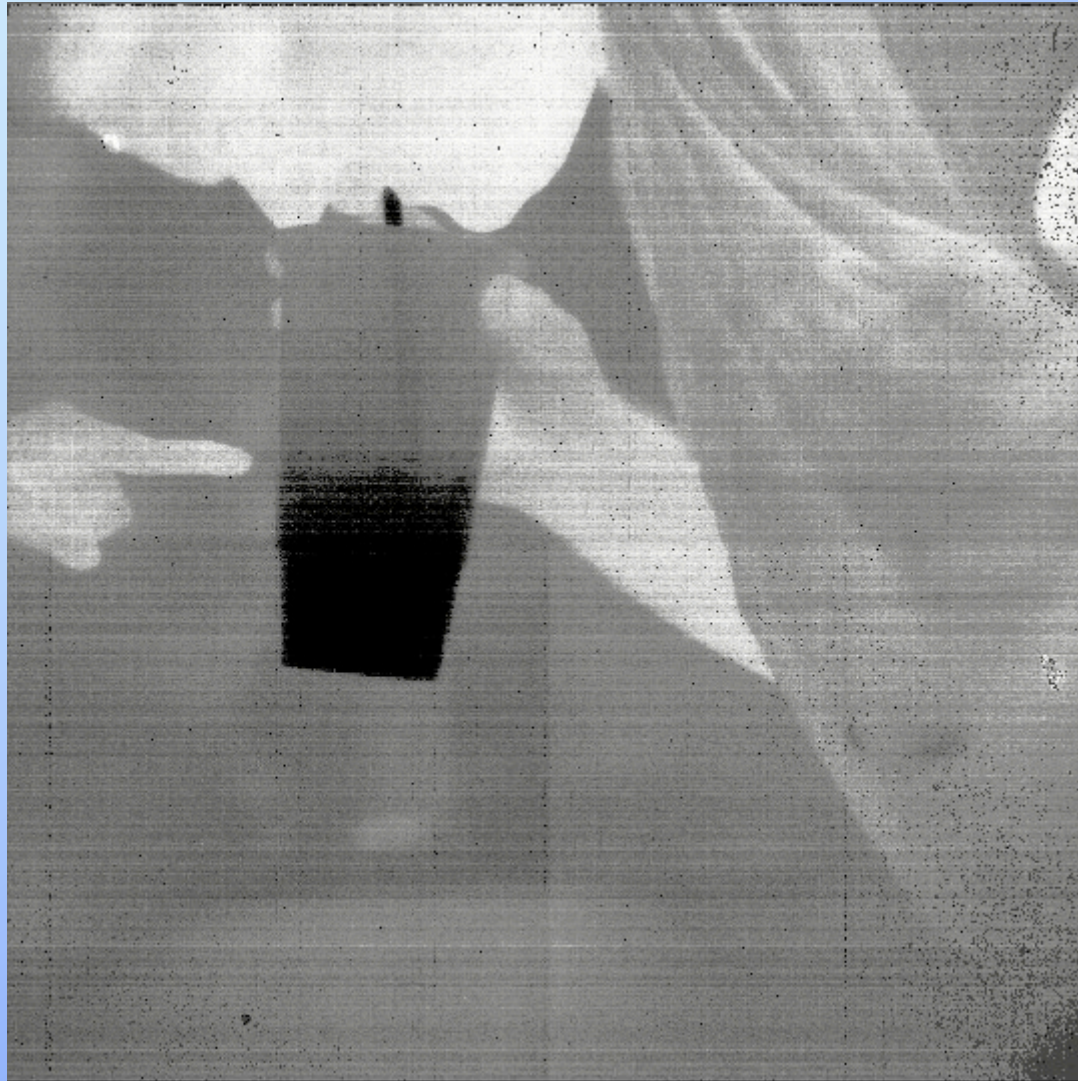
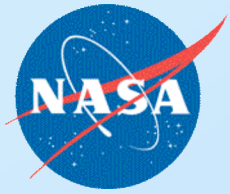
- **Hybridized 5 arrays from a single wafer**
  - 2 hybrids exploded during cooldown
  - 1 hybrid cracked during backside thinning
  - 1 hybrid has an internal ROIC anomaly which severely impairs operation
  - 1 hybrid (unthinned) has an ROIC anomaly preventing integration time adjustment--most data acquired from this hybrid
- **New preamplifier/dewar exhibited excess noise**
- **Data acquisition system was limited to a 2 quadrant readout per frame**

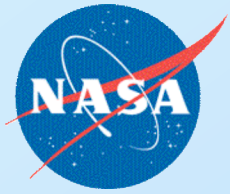
## Improvements

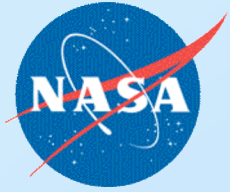
- **Fabricate new lot of arrays with a variety of recipes and hybridize to 1K ROICs (completed)**
- **Refined our thinning and packaging process**
- **Data system has been reconfigured for simultaneous 4 quadrant display**
- **Noise has been eliminated**





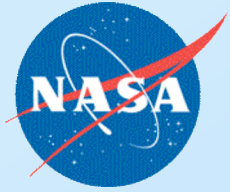






# Summary

- **First run yielded functioning devices but state-of-the-art arrays should be readily attainable ( $NE\Delta T < 15\text{mK}$ )**
- **Complete developmental cycle time was about 5 months**
- **Required minimal funding: wafer growth, masks (NRE), electronics upgrades (NRE), ROIC/hybridization**
- **Conversion efficiency followed prediction**
- **Operation at 75 K yielded dark current equal to 293K photocurrent**
- **Performed laboratory imaging**



# Acknowledgements

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- **This work was also supported by the Directors Discretionary Fund of the Goddard Space Flight Center.**
- **We are very grateful to Kadre Vural, Selmer Wong, Ellen Boehmer, John Montroy, Victor Gil and Lisa Fischer of the Rockwell Science Center for their support, for making their ROIC available to us and for their engineering efforts to fabricate the hybrids.**
- **We also want to thank John Liu of JPL for his efforts in thinning and packaging the arrays and Brian Ottens of Goddard for his assistance with testing the arrays.**